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NOTE ON METHODS OF OBSERVING POTENTIAL DIFFERENCES INDUCED BY THE EARTH'S MAGNETIC FIELD IN AN INSULATED MOVING WIRE

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In *Science*, **45**, 1917, p. 270, it was shown that the current induced in a rod about a meter long by the earth's vertical magnetic field, could be made surprisingly evident by the aid of an ordinary galvanometer, synchronized with the period of the inductor pendulum, of which the rod acts as the bob of a bifilar metallic suspension, including the galvanometer. Thus with a galvanometer showing but 10^{-6} amperes per cm. of deflection, and with a common period of about 4 seconds, the double amplitude of the spot of light reached over 20 cm. per average knot of speed of the rod. Similar results must be obtainable in case of a ship, where the charges accumulating at the ends of a long transverse rod may be tapped off into the water; or in case of a train where the tracks are available for dissipating charge. If, however, the rod is insulated, the determination of the potential difference in question is quite difficult. We made many attempts, as for instance the dissipation of charge from the ends by radium, electric incandescence, etc., the magnetic screening of parts of a circuit, etc., all to no practical effect. It seemed necessary therefore to carry the charge from end to end of the wire bodily; i.e., to reverse the principle of any type of induction electric machine, possibly with the additional object of securing intensification. Here also we have no ultimate success to record; but the secondary results are not devoid of interest, the idea being to construct, with precision, a large intensifier to pick up whatever electrostatic potentials may momentarily or permanently exist in the vicinity.

Simple Apparatus.—The apparatus (fig. 1), producing current is essentially cylindrical in shape, large and capable of revolving around an axle a with considerable speed. The electrical parts are of light metal, all insulated or screwed firmly to insulating discs attached to the axle. This frame work will not be shown in the figures.

A, A', A'', A''' are four insulated plates adjusted like the staves of a barrel, each making up about $\frac{1}{4}$ of its cylindrical area. Hence if the diameter of the barrel is D and its length L the area of each segment is $A = \pi LD/n$, if there are n segments. The plates A, communicate by means of metallic rods s, s', s'', s''', with the commutator segments or posts c, c', c'', c''', each system, A, s, c, etc., being insulated.

When the barrel revolves, a pair of brushes $b\ b''$ serve to put the two segments $A\ A''$ momentarily in contact when in the horizontal position. A similar pair of brushes b' b''' put the segments A' A''' momentarily in contact when in the vertical position. These brushes lead to the inclosed sensitive galvanometer G. Hence there will be two contacts for each pair of segments A for each rotation. B, B' are auxiliary insulated armatures and here removed.

Let the earth's vertical field be H and suppose the corresponding insulated metallic spokes s s'' in contact through b b''. Suppose the barrel to move forward as indicated at v in the direction of its axis, i.e., out of the diagram. Then there will be an induced electric field F in the direction A'' s'' s A, due to the cutting of the earth's vertical field. The result of the momentary contact is thus a positive charge q on A and an equal negative charge on A''.

When as a result of the rotation of the drum around its axis, the segments reach the position A' A''' electromagnetic induction ceases and the field F from this source is zero. Hence on momentary contact the charge will pass through the galvanometer G. With continued rotation this process is indefinitely repeated, so that a nearly continuous current flows through G; but there is no intensification.

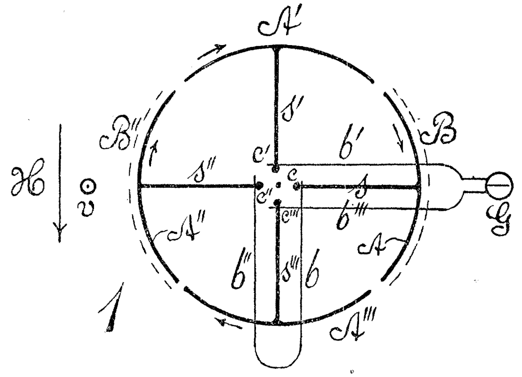


FIG. 1

Elementary Estimate.—Let the drum move in the direction of its axis with a speed v, so that the spokes $s + s'' = D$ cut the earth's vertical field H at this rate. Hence if the difference of potential between the plates A and A'' is V, when c and c'' are in contact

$$V = HDv \text{ elm. units.} \tag{1}$$

Again when c and c'' are insulated A and A'' may be considered the plate of a condenser and so long as the field within may be considered as virtually uniform, we may estimate by Gauss's theorem

$$q = \frac{AV}{4\pi D} = \frac{A}{4\pi}\,\frac{Hv}{3 \times 10^{10}} \text{ electrostatic units} \tag{2}$$

where q is the positive charge on the area A. Finally if the drum rotates around its axis a with the speed of N turns per second and if there are n segments, A, the corresponding mean current passing through the galvanometer, with inclusion of the value of A above, on reducing to practical units will be

$$I = NDLHv/3.6 \times 10^{20} \text{ amperes} \qquad (3)$$

Let $N = 100$; $D = 100$ cm.; $L = 100$ cm.; $H = 0.4$ dynes per unit pole; $v = 50$ cm./sec. or about 1 knot. Then

$$I = \frac{10^2 \times 10^2 \times 10^2 \times .4 \times 50}{3.6 \times 10^{2D}} = 5 \times 10^{-14} \text{ amperes, nearly.}$$

i.e., the current traversing the galvanometer per knot of axial motion through the earth's vertical field would scarcely be perceptible by an extremely sensitive galvanometer.

In our trial of the apparatus we used a disc pattern like figure 3, putting both a galvanometer and a telephone in series, at G. On charging auxiliary armatures like B, B'' in figure 1, with a small Wimshurst machine, a loud rattle was immediately heard in the telephone and the galvanometer showed an average current of 2×10^{-6} amperes at about 10 (or less) rotations per second. This slowly dropped owing to leakage of charge from the armatures; but at least 10^{-6} amperes persisted indefinitely. Discharging the armatures was followed with immediate permanent silence in the telephone. If we estimate the difference of potentials of the armatures as 10^4 volts, and the earth's field H (as above) to supply 5×10^{-5} volts, the latter should produce 5×10^{-5} $(2 \times 10^{-6}/10^4) = 10^{-14}$ amperes, which is of the order of values computed. Charging the armatures with 25 volts from a storage battery produced no result, as was to be expected.

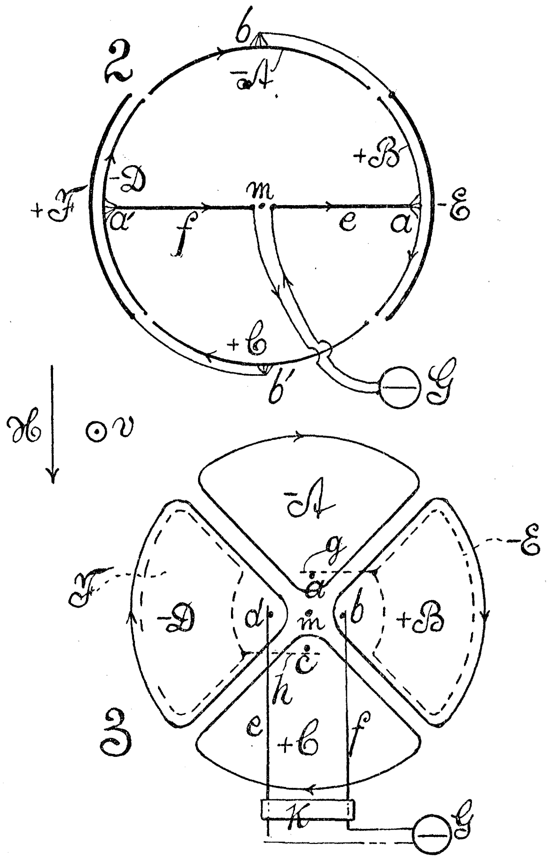
Intensification.—The drum was now to be modified as suggested in figure 2, though the experiments below were carried out with the disc form, figure 3, which is more easily constructed. All contacts must be synchronous and momentary.

In the disc type of machine (fig. 3) (as here constructed about 2 feet in diameter), A, B, C, D (in front) are the segments, rotating around the axis m, and E, F the armatures behind the diagram. The metallic posts or commutators a, b, c, d stick out normally from the disc both in front and behind it. The vertical brushes d and b touching diametrically opposite posts in front successively, include the galvanometer, etc., G, K being an insulating holder. The horizontal brushes, g and h, in metallic connection with E and F, respectively, touch the other two posts successively behind the disc and store the charges of A and C on E and F. H shows the earth's magnetic field and v the motion through it.

If we suppose that any charge on the armature E, for instance, induces the same but opposite charge on the segment B, the charges successively passing through the galvanometer for each quarter turn may be scheduled in such a way that the sum is a geometrical progression. Thus for N turns $Q = \Sigma q = (4/5)k^N q$ coulombs, nearly, where k is a large empiric constant depending on the method of initial charging and on the effective capacity of the armature-quadrant condenser.

Finally if there are N turns per second and $n = 4$ segments, the average current is in the first second:

$$I = k^N DLHv/1.8 \times 10^{21} \text{ amperes.}$$



FIGS. 2 AND 3

Thus even if $N = 10$ turns for 1 second, 20 turns for 2 seconds, etc., the current would soon be appreciable.

Observations with the Intensifier.—The telephone and galvanometer may be inserted together and their indications as to intensity are identical; but the galvanometer additionally shows the sign of the current. The average current of 10^{-7} amperes could still be easily heard in the telephone. The electroscope and electrometer were also tested; but these instruments are unsuitable as on open circuit the potential may suddenly rise to sparking values and ruin them.

Great care was taken to secure all insulators *firmly* and to allow only metal appurtenances (brushes) to touch each other.

The sounds (taps) were usually strong on starting the intensifier. As the speed increases to about 5 or 10 rotations per second a maximum of current was reached. This may be an average current of $\pm 10^{-5}$ amperes or more, as specified. The current frequently has an approximately regular period of reversal; as for instance (L, low current, here about -2.5×10^{-6} amperes; H, high current, $+5 \times 10^{-6}$ ampere, both fluctuating).

Successive currents.............	L	H	L	H	L	H	L	H	L	H	L	H, etc.
Period of each (seconds)........	25	30	30	30	30	35	45	35	40	35	45	35 etc.

The current is zero when the armatures are metallically connected. This shows that stray magnetic lines from the motor are without *direct* effect, a conclusion which was further tested by supplying stationary looped magnetic lines from a strong horseshoe magnet. Left to itself the machine picks up potentials either from within itself, incidentally, or from the room or surrounding walls in cold weather; and these are much higher than any which can be produced with a moving magnetic field. The machine, thoroughly flame-cleaned on both sides, with armatures in contact, soon charges itself, the maximum potentials being usually approached by successive alternations of rapidly increasing amplitude. Finally sparks appear at the brushes. If a bunsen flame is near, its depolarizing effect is appreciable at about a foot; the machine ceases to function at about six inches. Only under favorable conditions were we able to build up potentials from the induction of a small horseshoe magnet. It is obvious therefore that before putting such an apparatus to the final test it will have to be constructed with precision and experiments made in an environment free from stray potentials, with elimination of voltaic potentials, etc., in the parts, as everything of this nature is so quickly assimilated and intensified. As to the means of rating the value of the inducing potential, the current obtained on disconnecting the armatures for a definite small interval of time suggests itself.

The efficiency is enormously increased by diminishing the distance between the armatures and the rotating segments (condenser) though in the above improvised apparatus it was not possible to approach closer than an average half inch.